Ordovician Conodonts from the Watonga Formation, Port Macquarie, Northeast New South Wales

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Conodonts of Middle to Late Ordovician age, obtained from cherts of the Watonga Formation exposed in the Port Macquarie Block of the Mid North Coast region of New South Wales, establish this unit as the oldest biostratigraphically-dated part of the southern New England Fold Belt subduction-accretion complex. Correlation of the Watonga Formation with the Woolomin Formation, faunas from which are no older than Pridoli, cannot be sustained. This revised age provides evidence of possible early Palaeozoic subduction-accretion in this region at the same time as arc magmatism, volcaniclastic sedimentation and exhumation of high-pressure metamorphic rocks were proceeding further west.

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INTRODUCTION

Port Macquarie is situated approximately 350 km north of Sydney, geographically located in the Mid-North Coast region of New South Wales and geologically in the southern New England Fold Belt (Fig.1a). South of the township, the Watonga Formation (Leitch 1980), that has been invaded by minor intrusions and serpentinite bodies, makes up the eastern portion of the fault-bounded Port Macquarie Block of Leitch (1974). The Watonga Formation is well exposed along the coastline between Port Macquarie and Tacking Point (Fig.1b) where it comprises mostly broken formation inferred to result from disruption of a once-stratified sequence of basalt, chert, siliceous mudstone, siltstone, sandstone and conglomerate. Several chert-dominated units can be mapped west from the coast, and locally little-disrupted basalt forms sections at least several tens of metres thick. Previous descriptions of the rocks of the Watonga Formation include those of Barron et al. (1976), Leitch (1980) and Och et al. (2005), who all concluded that the formation comprises a part of the accretionary – subduction complex that is widely exposed in the New England Fold Belt east of the Peel-Manning Fault System (Fig. 1c).

The Watonga Formation is unconformably overlain by early Triassic rocks of the Camden Haven Group but is faulted against all earlier stratified rocks (Leitch 1980). A Late Silurian to Late Devonian age has been assigned to the Watonga Formation, based on lithological correlation with the Woolomin Formation of the Tamworth region (Leitch 1980), undescribed palaeosceniid radiolarians from chert at Watonga Rocks (Ishiga et al. 1988a) and conodonts reported from chert at Tacking Point (Ishiga et al. 1988a, b). In this paper we present new conodont data that more accurately constrains the age of Watonga Formation chert, and reassess previous microfossil identifications from that formation and its possible correlatives in order to reinterpret its tectonic significance.

CHERT IN THE WATONGA FORMATION

Chert occurs widely in the Watonga Formation, in mappable chert-rich zones (Fig. 1b), in shear-bounded blocks associated with basalt and/or mudstone, and as discrete tectonically isolated blocks. Mass flow deposits, although uncommon, also contain chert clasts. Most exposures occur as 'ribbon chert' characterised by discontinuous stratification with individual beds 5 mm to 200 mm thick intercalated

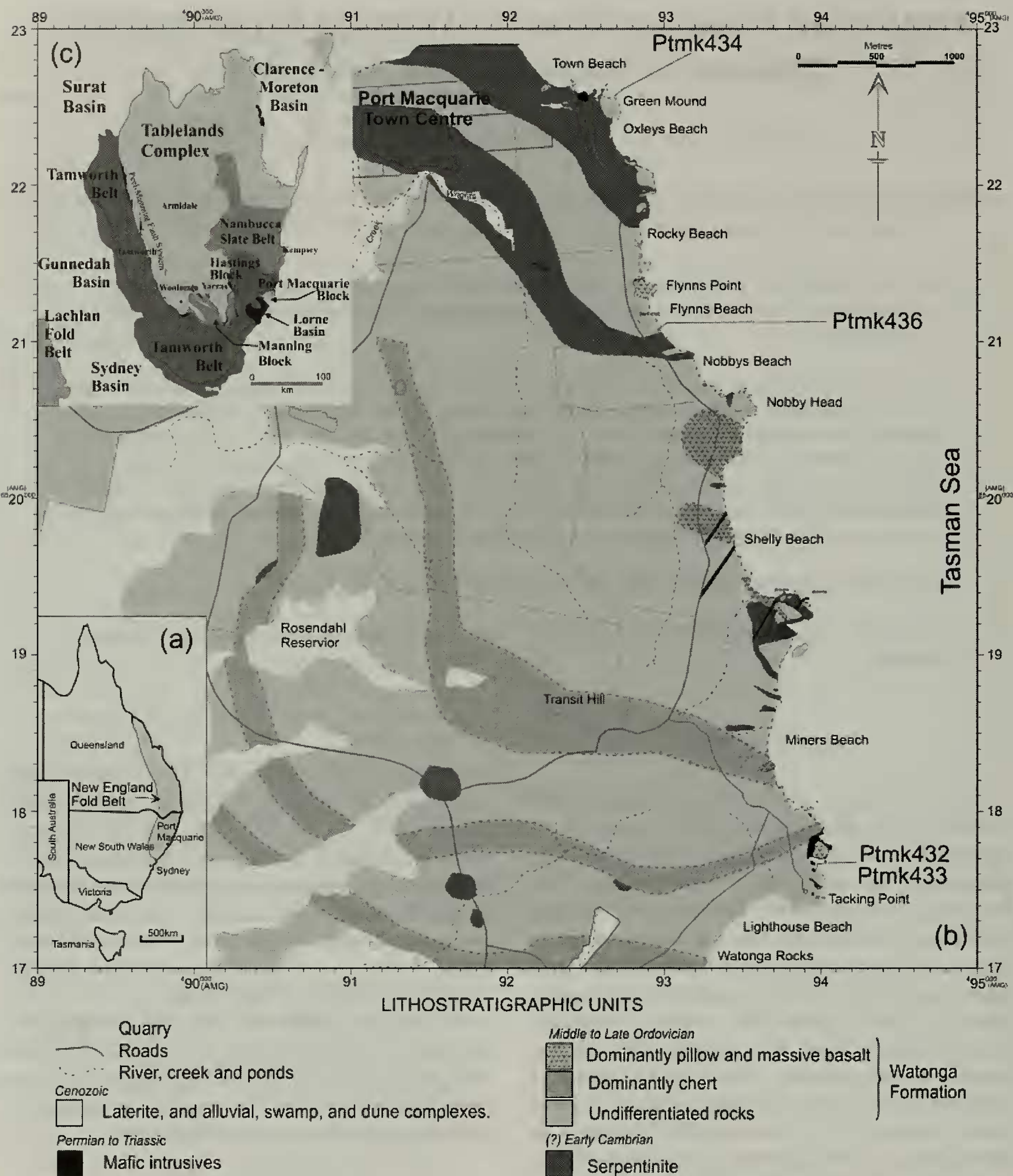


Figure 1. (a) Location of Port Macquarie in the southern part of the New England Fold Belt. (b) Geological map of the northeast corner of the Port Macquarie Block showing localities sampled for conodonts. Map grid is AMG-66. (Mapping by D. Och). (c) The Port Macquarie Block and adjacent tectonic elements of the southern New England Fold Belt. Pale grey (Tableland Complex) is mostly accretionary – subduction complex terranes, grey (Manning Block and Nambucca Slate Belt) Early Permian overlap sequences, and dark grey (Tamworth Belt) Palaeozoic arc and forearc deposits. Widespread latest Carboniferous-Triassic granite bodies omitted.

with thinner recessive dark mudstone units (some mere films), and together forming irregular flat lenses rarely exceeding 0.5 m in length (Figs 2a, b). Less common thicker beds (up to 1 m) are more laterally continuous but change thickness along strike and mostly lens out or are terminated by faults and shears

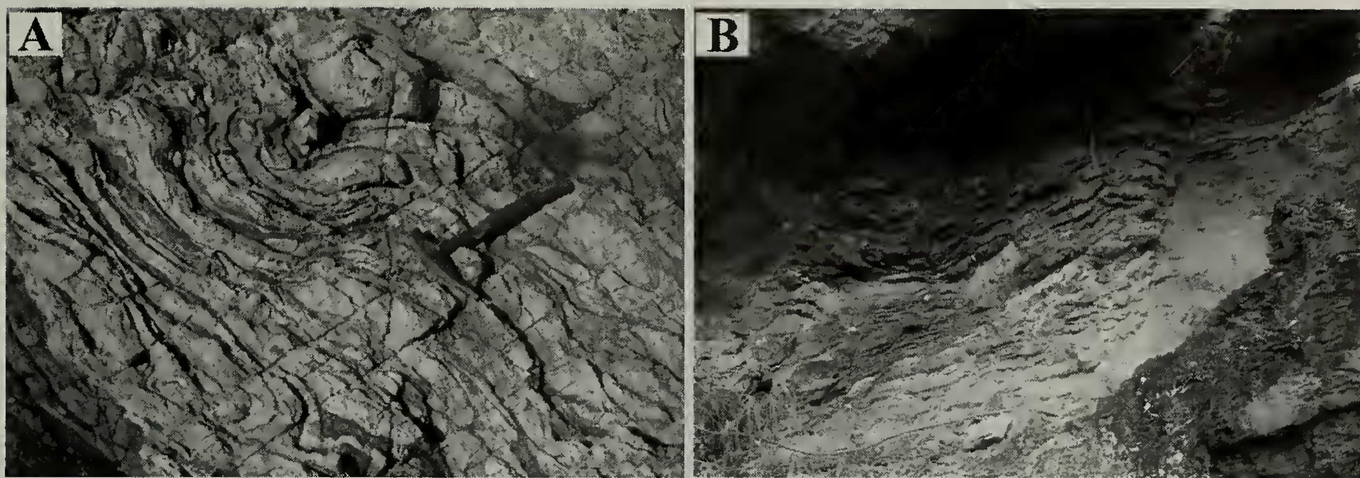


Figure 2. (A) Ribbon chert showing discontinuous character of stratification, thickness variation in individual layers, and irregular folds, all suggestive of soft sediment deformation. Tacking Point (Grid reference 493930 mE 6517660 mN, location of sample Ptmk 433). (B) Broken formation of prominent chert lenses and recessive sheared mudstone matrix offset by a late fault, Town Beach (Grid reference 492600 mE 6522550 mN, location of sample Ptmk 434).

within individual exposures.

The chert is highly variable in colour, with white and grey predominating but including red, orange-brown, green and black varieties. Primary sedimentary structures other than relic bedding are absent. Widespread disharmonic mesoscopic folds, lacking any signs of axial surface structure, of variable orientation, and of a style ranging from box-shaped to fluidal, are interpreted as pre-consolidation slump structures. Ghosts of radiolarians are preserved in some specimens but others consist solely of fine anhedral quartz grains with a dusting of iron oxide minerals. Samples collected from Tacking Point (localities Ptmk 432 & 433) are strongly recrystallised due to local thermal metamorphism, whereas those from Flynns Beach and Town Beach (Ptmk 436 and Ptmk 434, respectively), although highly veined, show only the effects of the low grade regional alteration that has affected all of the Watonga Formation.

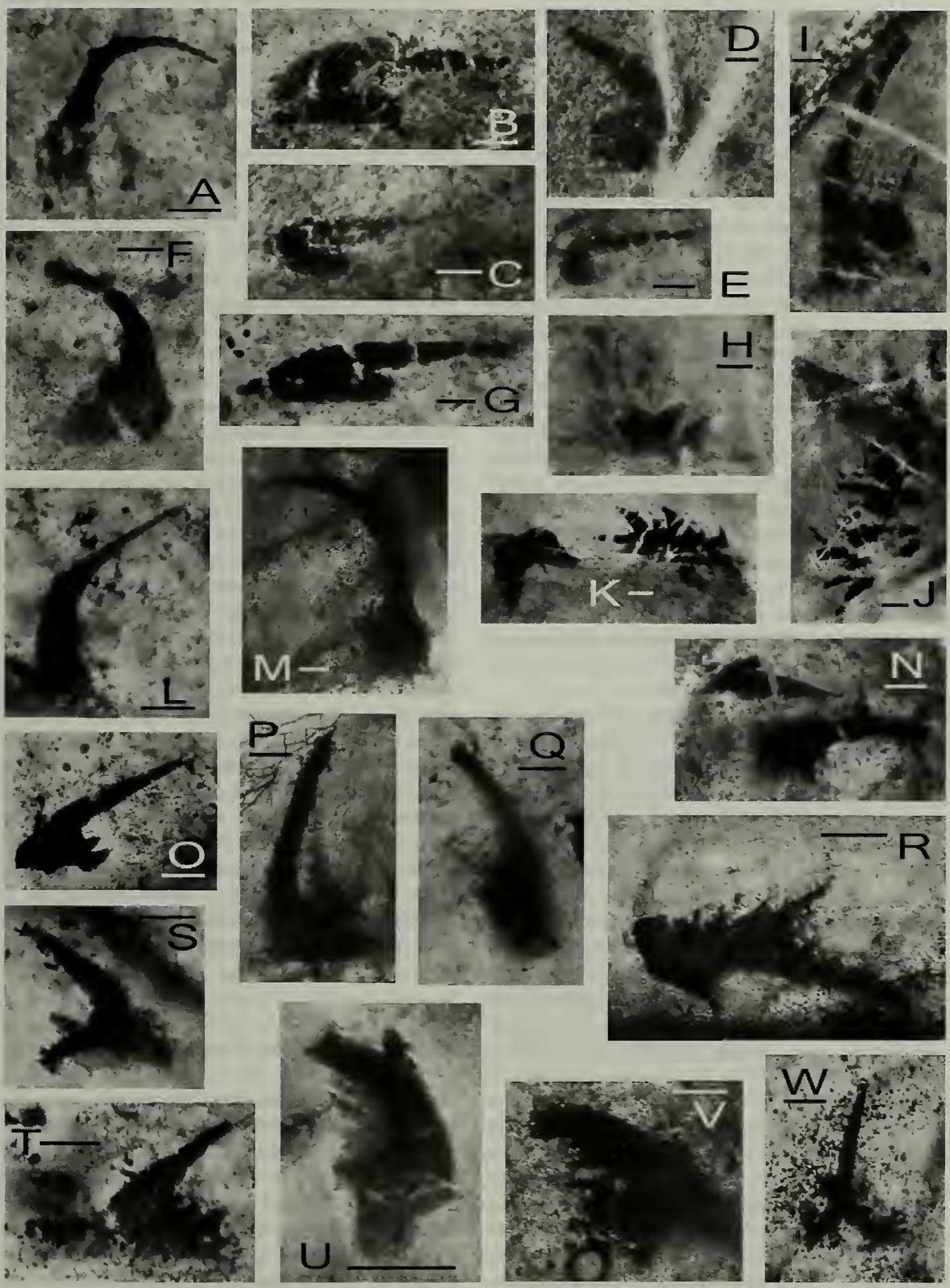
PREVIOUS AGE-DATING OF THE WATONGA FORMATION

Accurate dating of the rocks of the Port Macquarie Block is important in understanding the geological evolution of the region, better defining the timing of accretion, determining relationships of the block to other structural units of the southern New England Fold Belt and establishing tectonic relationships with other early Palaeozoic elements in eastern Australia. Leitch (1980) first defined Palaeozoic lithostratigraphic units in the area south and west of Port Macquarie, and recognised the chert-rich Watonga Formation as having lithological similarities to the Woolomin Formation exposed south of Tamworth (Fig. 1c). On this basis he assigned a generalised early Palaeozoic age to the Watonga Formation although biostratigraphically useful fossils had not been obtained from these rocks. Prior to the present investigation, biostratigraphic data for the Watonga Formation in the Port Macquarie Block was limited to a record of the conodont *Belodella* spp. (indicative of a generalised Late Silurian-Early Devonian age) recovered from red cherts at Tacking Point, and late Frasnian (Late Devonian) palaeosceniid radiolaria including *Palaeorubus hastingensis* Ishiga, 1987 (in Ishiga et al. 1987) from chert at Watonga Rocks (Ishiga et al. 1988a; b). Although this material was never illustrated, these ages have been widely accepted as dating the Watonga Formation.

BIOSTRATIGRAPHY OF THE WOOLOMIN FORMATION

In the light of the inferred lithological correlation of the Watonga Formation with the Woolomin Formation of the Tablelands Complex to the west near Tamworth, it is important to reassess available data on ages from the latter unit. Major advances in dating the Woolomin Formation resulted from a collaborative project between geologists from the University of Sydney and a consortium of Japanese universities in the mid-1980s. Microfossils, including radiolaria and conodonts, were extracted from cherts by dissolution in hydrofluoric acid; the results were presented in a detailed report (Ishiga et al. 1988b) with significant findings summarised in Ishiga et al. (1988a). Conodonts identified by these authors as *Ozarkodina eosteinhornensis*, *Belodella* cf. *resima* and *Walliserodus* sp. were recovered from one locality (WA-50) in red bedded chert north of Woolomin. This assemblage, although limited, is clearly indicative of a Late Silurian (Pridoli) age due to the presence of the nominate species of the *eosteinhornensis* zone, now referred to as *Ozarkodina remscheidensis eosteinhornensis*. Additional specimens illustrated by Ishiga et al. (1988b) confirm the identity of this species. However, *Belodella resima* is a characteristic Early Devonian form, not known to occur in the Silurian and typically displaying strong marginal costae not observed in the specimens from the Woolomin Formation. The four specimens illustrated from locality WA-50 by Ishiga et al. (1988b, pl. 3 figs 9-12) are insufficiently well-preserved to show diagnostic features of the Late Silurian species *B. anomalis*, so they are probably best assigned to *Belodella* sp. The specimen figured by Ishiga et al. (1988b, pl. 3 fig. 8) as *Walliserodus* sp. is more likely to be the non-denticulate M element of this *Belodella* as it appears to lack the pronounced costae on lateral faces that characterises *Walliserodus*. Ishiga et al. (1988a, fig. 2p) illustrated a sharply-keeled element with triangular cross section, planar to slightly concave lateral and posterior faces and a deep basal cavity that they also assigned to *Walliserodus* sp. from the same locality; it is here identified as the long-ranging genus *Coelcerodontus* sp. Four additional fragments of S elements of ozarkodinids, depicted by Ishiga et al. (1988b, pl. 3 figs. 13-16), are too incomplete for identification but are consistent with Late Silurian species. The Pridoli age inferred for cherts at locality WA-50 contrasts with an early Carboniferous age determined for similar cherts south of Woolomin (locality 29 of Ishiga et al. 1988a; b) based on the occurrence of the radiolarian *Albaillella* sp. Given the highly imbricate structure of this area the possibility of infaulting of younger units as occurs north of Woolomin cannot be discounted (cf. Cawood 1982). While the Pridoli age determined for the Woolomin Formation is generally consistent with the previously accepted age of the Watonga Formation, new data reported here suggest that the Watonga Formation is considerably older.

Figure 3 (RIGHT). Conodonts from Watonga Formation chert, Port Macquarie Block
A – G from locality Ptmk 432, Tacking Point; A. *Panderodus recurvatus*?, MMMC 4348; B. eobelodiniform element of *Belodina* sp., MMMC 4349; *C. Paroistodus* sp., MMMC 4350; D. drepanoistodid element in oblique view, showing strongly flared basal cavity (specimen intersected by V-shaped cryptocrystalline vein), MMMC 4351; E. indeterminate coniform element, MMMC 4352; F. drepanoistodid element with expanded base, MMMC 4353a; G. strongly reclined M element, possibly related to *Ansella* sp., MMMC 4353b. H – K from locality Ptmk 434, Town Beach; H. unidentified platform? element with two prominent peg-like denticles (remainder of specimen, in upper part of figure, is out of plane of focus), MMMC 4355; I. unidentified S element, possibly referrable to *Periodon*, showing fine denticles but apparently incomplete posteriorly, MMMC 4356; J. extensively fragmented element of *Belodina*, anterior to right, MMMC 4357; K. lateral view of unidentified platform? element with discrete peg-like denticles comparable with those shown in H, MMMC 4358; L – W from locality 436, Flynns Beach. L. *Panderodus* sp., MMMC 4359a; M. *Panderodus recurvatus*? showing curvature of cusp comparable with specimen depicted in A (although expanded base is more reminiscent of drepanoistodid), MMMC 4360a; N. *Strachanognathus parvus*, interpreted as split along cusp and dextrally separated, MMMC 4361; O. unidentified element with two prominent denticles on lateral process, MMMC 4359b; P. *Protopanderodus*? sp. with posteriorly-extended base, MMMC 4359c; Q. indeterminate coniform element resembling *Dapsilodus*, MMMC 4362; R. *Periodon aculeatus*, S element (note that cusp is displaced into section below plane of focus), MMMC 4360b; S. *Phragmodus*? sp., P element, MMMC 4363a; T. unidentified Pb element (anterior process unclear, but note three or more discrete denticles on posterior process), MMMC 4364; U. *Pseudobelodina* sp., MMMC 4360c; V. *Pseudobelodina* sp., MMMC 4363b; W. unidentified Sa? (symmetrical) element, MMMC 4365. All elements illustrated in lateral view unless otherwise indicated. Scale bar for each specimen represents 100 μm. Chert sections are housed in the microfossil reference collection (MMMC) of the Geological Survey of NSW, Londonderry Geoscience Centre, Londonderry 2753.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NEW DATA ON THE AGE OF THE WATONGA FORMATION

More than 25 conodont elements were observed in cherts collected from outcrops of the Watonga Formation on the coast immediately south of Port Macquarie (see Fig. 1b for sample locations). Unlike previous investigations, these microfossils were not dissolved out of the cherts using HF. Instead, the technique used involved preparing four or five large (7.5 x 3.8 mm) thin sections from each sample, cut parallel to bedding planes of the cherts, and ground to a thickness of about 50-60 microns. Both sides of the finished thin section were carefully examined with a binocular microscope using transmitted light. This method (first developed by Ian Stewart of Monash University) has previously been employed to investigate conodont biostratigraphy in cherts exposed in the Narooma area on the NSW south coast (Glen et al. 2004), and from the Tamworth Belt south of Tamworth (Fig. 1c) from where Stewart (1995) determined a Middle to early Late Cambrian age for conodonts in spiculitic chert of the Pipeclay Creek Formation. Although conodonts found in this way can only be observed in the plane of section in whatever random orientation is presented to the viewer, the thin section technique has the distinct advantage of preserving extensively fractured elements that would be destroyed by dissolution in HF.

Samples Ptmk 432 and Ptmk 433 were obtained from grey-black chert outcrop at Tacking Point (Fig. 1b). Although the two cherts closely resemble each other, sample Ptmk 433 was devoid of microfossils whereas Ptmk 432 yielded eight elements. One of these (Fig. 3B) is identified as the eobelodiniform element of the Late Ordovician genus *Belodina.* Associated *Paroistodus* (Fig. 3C) and unidentified drepanoistodids are consistent with this age.

A further four conodont elements were found in sections cut from sample Ptmk 434, a grey-black chert at Town Beach. Although extensively fractured, the belodiniform element of *Belodina* (Fig. 3J) is readily identifiable, and provides support for recognition of another element from the *Belodina* apparatus in sample Ptmk 432. Elsewhere in New South Wales several species of *Belodina* have been identified from limestones of Gisbornian and Eastonian age (Late Ordovician) in the central part of the state. *Belodina* is also known from limestone olistoliths of Eastonian age in the Wisemans Arm and Drik Drik formations of the Tablelands Complex and Tamworth Belt, respectively, in the New England Fold Belt (Furey-Greig 1999; 2000). An unidentified element illustrated in Fig. 3I most closely resembles a specimen identified as *Phragmodus* sp. by Iwata et al. (1995: figure 2g) from the Ballast Formation east of Cobar in central NSW, though the Town Beach example is unlikely to be that genus (R.S. Nicoll, pers. comm.. 2006). The Ballast Formation fauna was tentatively assigned a Late Ordovician age by Iwata et al. (1995).

Orange-brown chert from Flynns Beach (sample Ptmk 436) was the most prolific of the samples examined, yielding 14 conodont elements. *Periodon aculeatus* (Fig. 3R) has a range of late Darriwilian (late Middle Ordovician) to early Gisbornian (early Late Ordovician). *Pseudobelodina* (Fig. 3U,V) and *Strachanognathus parvus* (Fig. 3M) also occur over this interval, which is consistent with ages of other genera tentatively identified from this locality. Thus locality 436 may be slightly older than both localities 432 and 434 which could be identical in age.

In summary, the maximum age range indicated for cherts from the Watonga Formation appears to extend from late Darriwilian to somewhere within the Late Ordovician, possibly as young as the end of the Eastonian (middle Late Ordovician). There is no evidence for Silurian or Devonian ages in these samples, thus conflicting with the previously reported occurrence of *Belodella* spp. (Ishiga et al. 1988a; b). Several Ordovician conodont elements, such as those of *Ansella* and *Belodina* (the latter newly identified from Tacking Point) resemble *Belodella,* though without illustrations of specimens that were obtained from the Watonga Formation by Ishiga it is impossible to clarify whether or not this was misidentified. Palaeosceniid radiolaria obtained from the Watonga Formation at Watonga Rocks include *Palaeorubus hastingensis*, otherwise known only from late Frasnian rocks at Yarras in the western part of the Hastings Block, to the west of the Port Macquarie Block (Ishiga 1988). Until more information is available concerning the age range of this form, the Late Devonian age accorded the unit here cannot be regarded as well established.

TECTONIC IMPLICATIONS

Although no coherent stratigraphic sequence has been demonstrated in the Watonga Formation, the association of chert and mudstone with basalt mainly of mid-ocean ridge magmatic affinity (Och et al. 2004), and interbedded graded volcaniclastic sandstone and siltstone, is readily interpreted as the product of sea-floor spreading, the accumulation of pelagic oceanic rocks, and trench deposition on a plate undergoing subduction. The early deformational style of the Watonga Formation, involving progressive disruption of the rocks in a continuum from soft sediment deformation (Fig. 2a) to shearing and stretching producing broken formation (Fig. 2b), is consistent with accretionary – subduction tectonics. Furthermore the Watonga rocks are of similar structure to that of many units considered to be of subduction – accretion origin, including pre-Permian rocks from elsewhere east of the Peel-Manning Fault System in New England.

The Middle – Late Ordovician chert samples Ptmk 432, 434 and 436 are the oldest biostratigraphically dated rocks recorded from the New England accretionary – subduction complex, and rule out correlation of the Watonga Formation with the Woolomin Formation chert from which only Late Silurian and younger ages are known (see preceding discussion). The Ordovician chert ages provide a minimum age for the oceanic plate sediments that were subducted, and raise the possibility that the Watonga Formation was accreted in the early Palaeozoic, at which time arc magmatism and volcaniclastic sedimentation were proceeding further west in the New England Fold Belt (Cawood 1983; Furey-Greig et al. 2000; Offler and Shaw 2006) and in the eastern Lachlan Fold Belt (Glen et al. 1998), and high pressure metamorphic rocks now embedded within serpentinite bodies at Port Macquarie were being exhumed under blueschist facies conditions (Fukui et al. 1995; Och et al. (2003). Scheibner (1998) and Glen (2005) have suggested that the blueschists are accretionary rocks that formed outboard of the Macquarie Arc in the eastern Lachlan Fold Belt. Ordovician accretion of the Watonga Formation rocks would be consistent with them constituting a fragment of the Narooma accretionary complex postulated to extend into New England by these workers. The Ordovician age for the Watonga Formation also provides a potential source for chert blocks widespread in the (?) Early Devonian Wisemans Arm Formation (Leitch and Cawood 1980; Furey-Greig 1999).

The Watonga Formation is isolated from the remainder of the New England accretionary complex by the allochthonous Hastings Block (Fig. 1b) that was moved north from along strike of the southern Tamworth Belt in the Late Palaeozoic (Schmidt et al. 1994). It is likely that the Watonga Formation was similarly displaced from a position much closer to the Peel-Manning Fault System, in the vicinity of which the Early Palaeozoic rocks of the New England Fold Belt are concentrated. The central and eastern parts of the New England accretionary – subduction complex have yielded chert samples no older than latest Devonian (e.g. Aitchison and Flood 1990; see summary in Fergusson et al. 1993, fig. 12).

CONCLUSIONS

Conodont faunas identified in bedding-parallel thin sections from Watonga Formation cherts of the Port Macquarie district are of Middle-Late Ordovician age, thus making these cherts the oldest biostratigraphically dated rocks from the extensive accretionary – subduction complex of the New England Fold Belt. The dates provide a minimum age for the oceanic plate that was subducted, and raise the possibility that the Watonga Formation was accreted in the early Palaeozoic at the same time as arc magmatism and volcaniclastic sedimentation were preceding further west. A reassessment of the age of a conodont fauna from the Woolomin Formation in the southwestern part of the accretionary complex indicates it is of Late Silurian (Pridoli) age, and hence substantially younger than the Watonga Formation. Thus the previously conjectured correlation between the Woolomin and Watonga formations can no longer be sustained. The Watonga Formation was probably moved north in the late Palaeozoic during displacement of the Hastings Block along strike from the southern Tamworth Belt.

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